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Saline agriculture in the Arabian Peninsula: Management of marginal lands and saline water resources

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Abstract
Productive land and renewable fresh water resources in the Arabian Peninsula are limited and are being exploited at a rapid rate, with agriculture utilizing >85% of fresh water resources. Saline and brackish water resources, marginal lands and plants capable of growing and producing an economic crop under the harsh conditions of the Arabian Peninsula, are abundant and expected to alleviate the mounting pressures on fresh water resources and prime agricultural lands. There is a need to demonstrate the value of saline water resources for the production of environmentally and economically useful plants and crops and to transfer the results to national research services and communities in the Arabian Peninsula. A regional strategy is needed to utilize the rapid advances in the use of saline water for irrigation, including development of improved irrigation systems, water management, control of salinity in root zone, and utilization of genetic resources of salt tolerant plants and halophytes. An integrated and holistic approach that reflects local and regional ecosystems' relationships is proposed. It addresses the long-term sustainability of saline agriculture and aims at developing decision-support systems to further focus attention on gaps in existing knowledge and provides flexible and efficient means for evaluating alternative options in saline agricultural production in the Arabian Peninsula.

Key words: Agricultural lands, control of salinity, irrigation, halophytes, salt tolerant plants, holistic approach, water resources.

Introduction
Throughout history, the unavailability of water in large parts of the Arabian Peninsula has affected the lives and livelihood of its inhabitants. A remarkable variety of adjustments to water supply fluctuations and deficits have been made by indigenous people over the years [1]. More recently, however, socio-economic development, high population pressure and the availability of modern water pumping and irrigation technology, as well as expanded urbanization and agricultural activity, have placed substantial strains on water resources of most countries in the Arabian Peninsula [2-4]. High population growth rate, in combination with increases in per capita water consumption have contributed to increases in domestic water consumption. Most countries of the Arabian Peninsula have similar physiographic, social and economic characteristics, including extremely arid climates, sparse natural vegetation and fragile soil conditions. The natural water resources consist of limited quantities of run-off resulting from floods, groundwater in the alluvial aquifers and extensive groundwater reserves in the deep sedimentary aquifers. The supplementary non-conventional sources include desalination of sea and brackish water, and renovated waste water [5]. Fossil groundwater, a non-renewable resource stored in the sedimentary deep aquifers, is a main source of water in the Arabian Peninsula. Vast volumes of groundwater stored in deep aquifers serve as dependable sources of water for the central and northern regions of Saudi Arabia, and to a lesser extent, the other countries of the Arabian Peninsula. Deep groundwater reserves in the aquifers of the Arabian Peninsula are estimated at 2,175 billion cubic metres (bcm), with the major portion (1,919 bcm) located in Saudi Arabia. Recharge for all the deep aquifers is estimated at a very limited 2.7 bcm per year [6-7]. The mounting pressure on prime agricultural land and fresh water resources in the Arabian Peninsula to provide ever-increasing amounts of forage and horticultural crops is increasingly recognized [8]. In view of the rapid increase in demand for water, the potential for development of conventional fresh water resources is extremely limited; other alternatives such as waste-water reclamation and desalination processes have been developed for municipal and industrial use since the 1960s [5]. More recently, however, the potential of saline water, which has been neglected in water-resources studies, along with marginal land resources were considered for crop and forage production [8]. Available low- to moderate-saline water resources in the Arabian Peninsula, and indigenous and exotic salt-tolerant plants, if properly managed, can alleviate the pressure on the diminishing fresh water resources and provide a wide range of agricultural products and environmental benefits.

Agriculture and Irrigation in the Arabian Peninsula
With water becoming an increasingly scarce commodity in the Arabian Peninsula, it has now a big potential of becoming a limiting factor for agricultural, and even for industrial development [9]. The greatest challenge is the provision of fresh water supply to meet the agricultural, domestic and industrial sectors' demands. With groundwater resources over-exploitation and the limited capacity of desalination plants, planners are continuously searching for additional sources of water which can be used economically and effectively to promote further economic development. The policies of the Arabian Peninsula countries are clearly stated in the Joint Agricultural Policy for the Arab States of the Gulf Cooperation Council [10-13]. This policy is directed towards greater self-sufficiency in food and feed through increased agricultural production. This production can only be brought about through increased area of crops and numbers of livestock and/or increases in production

efficiency. These increases in production will only be realized by developing greater areas of irrigation and/or improvements in irrigation efficiency. Irrigated agriculture in the Arabian Peninsula has expanded very rapidly over the past 20 years in response to government policies for food self-sufficiency. Expansion rates of around 10% per year were very difficult to sustain in the long-term and placed considerable pressure on support services. The increase in area planted to horticultural crops ranged from 12 to 15% per year since 1980 [7-8], while around 4% of the increase has been in the area planted with date palms. There has also been a significant increase in the areas of the more salt-sensitive vegetables, melons and fruit trees. It is these more salt sensitive crops which will be impacted by the decline in water quality. Livestock production increased by about 2% per year since 1980. This level of increase could only be sustained through production of forage under irrigation. The increase in area of crops grown and number of livestock is through increased area of irrigation and improvement in productivity. The area under irrigation increased by 5% per year up until 1990, then by 1.2% per year thereafter [7]. This suggests that the increase, particularly in livestock has, in part, came from productivity improvements or importation of forage. Data are not readily available for the area of forest plantings (including roadside greening and landscape plantings); however, the areas have increased equally as rapidly as for agriculture, especially in and around major municipalities. There is a need to identify alternative agricultural production systems based on the use of brackish irrigation water and marginal land; these production systems need to be established as soon as possible if the current level of agricultural production has to be maintained. Countries with mature irrigated agriculture have developed the full range of technologies to support their industries [14]. These technologies include modern and operational irrigation systems, tools and expertise to apply and monitor the exact amount of water that has to be applied to meet crop water use, crops that are productive under the irrigation regime being used and strategies to minimize the impact of saline water on crop productivity. However, to transfer irrigation and salinity technology from one environment to another requires a broad base of expertise and understanding of the interaction between soil, water, climate and farming systems. Furthermore, systems must be developed to monitor the impact of the introduction of this new technology in ways that ensure maximum favorable impact on sustainability and profitability [15]. These technologies can be brought together in the Arabian Peninsula by way of multidisciplinary teams, acquisition, evaluation, assessment and transfer of information or expertise, and collaborative programs to train all people involved in the farming enterprise. This integrated approach will ensure that existing technologies in the world market are available to local farmers and producers while at the same time ensure that the new technologies required to underpin the long-term and sustainable development of saline agriculture are also available [13].

Future of Saline Agriculture in the Arabian Peninsula

With growing scientific and social recognition of the many diverse values of salt-tolerant plants, alternative agricultural production systems based on the use of saline water are being developed. However, there is still a critical lack of applied research that combines biological, physical, economic and social variables at the farm level [16]. Worldwide, there has been little research to support decision making about the long-term management and sustainability of "saline agriculture [14]." A major objective is to integrate technical, economic, social and policy elements of irrigated systems to maximize sustainable crop production whilst ensuring minimum environmental degradation. The real challenge is not only to provide answers to all problems of saline agriculture, but rather to establish and consolidate a research and development strategy strongly grounded in partnership with developing and developed country scientists. The intensive use of groundwater resources from shallow and deep aquifers to meet rising demand has led to further exploitation of water resources in excess of natural renewability and has contributed towards water-quality deterioration, especially in the coastal zones of most countries in the Arabian Peninsula [10-13]. Competition among industrial, municipal and agricultural sectors over utilization of available groundwater sources has created water deficits. Rising demand is not only placing pressure on water resources, especially the most easily accessible sources, but also brings about an entirely new progression of environmental concerns and their associated developmental cost. Total water demand for agriculture, industrial and domestic purposes is about 20 billion cubic metres (bcm). Agriculture accounts for the bulk of water use, followed by the industrial sector. The agricultural sector uses approximately 17 bcm; domestic water demand accounts for about 2,559 million cubic metres (mcm), whereas the industrial sector uses some 258 mcm [7]. Land degradation is a common problem throughout the Arabian Peninsula, resulting both from natural environmental factors and from the misuse of land. Periodic droughts along with extensive pressure from overgrazing, uncontrolled cultivation, fuelwood gathering, inappropriate use of irrigation water and sand encroachment have all contributed to land degradation in this region. A large part of the Arabian Peninsula is desert, and an increasing part of the permanent pasture areas is subject to erosion because of reduced vegetation cover. Overgrazing in desert areas is a major cause of plant cover loss, particularly in the northern parts of Saudi Arabia and the southern parts of Oman. Countries such as Bahrain have also lost substantial vegetation cover as a result of urbanization. The coastal plains of Oman have suffered a particularly sever loss of vegetation as a result of overgrazing. Desertification and land degradation, including soil erosion and salinization, have implications for the region's food security. The food gap in the Arabian Peninsula is among the highest in the developing world. With increased desertification coupled with the high population growth rates, this food gap will increase dramatically in the future, along with the high level of dependency on food imports for most countries [17].

Use of salt-tolerant plants: Selection for salt tolerance has been both a natural and managed process for millennia. Through time, plants have evolved from a saline environment to the present complex environments of soil, climate, and water and have provided the biodiversity that exists today, including the adaptation to different salinity conditions [16]. Salinity is a very dynamic attribute within our global environment and it has responded rapidly to human intervention. Irrigation, without proper technology, has resulted in millions of hectares of saline soils around the world, and elimination of natural vegetation. This has had consequent impact on the hydrologic balance which has rendered hundreds of millions of hectares susceptible to salinity. In an evolutionary context, plants have responded to different salinity regimes. Selection for salt tolerance has been practiced, most probably, since man first started crop production. Recently, however, the interest in selection for salt tolerance has increased remarkably as cultivation has intensified and food security became a major concern [18]. Globally there is a reasonable understanding of the relative salt tolerance of plants and of the mechanisms associated with salt tolerance. Moreover, there have been active research programs in many countries to identify plants with salt tolerance, which are of benefit as forages, horticultural crops, cereal production or greening. There has been extensive work carried out, and a good understanding has been developed of the relative salt tolerance of major commercial forages, cereals, vegetables, fruit crops and halophytes. This information is maintained within the scientific literature, and in a number of plant genetic resource collections around the world [16,19].

Irrigation and salinity technology: Rapid advances have occurred globally in the fields of irrigation systems, water management, control of salinity within the root zone and external impacts, and tools available for monitoring irrigation and salinity management [14, 20, 21]. These systems have been successfully packaged and widely used in many countries including the United States, Australia, South Africa and some European countries. Within the Arabian Peninsula, there are examples of highly efficient irrigation systems [3, 10], such as the center pivot and drip systems. On the other hand, there are many examples where the systems along with the management do not produce optimum irrigation efficiency. This is a problem experienced by water managers globally. When high salinity water is used for irrigation, the technology and the expertise required are a level higher than what is required for conventional irrigation and the impact of poor systems or poor management are much greater in saline areas where special irrigation technology is required, and therefore more visible.

Equipment specification and performance: There is a very wide range of normally useful irrigation equipment available which when subjected to various environmental conditions such as system pressure, wind, temperature and water quality will not perform as predicted. The hydraulic properties of the delivery system are critical in being able to deliver water in a known and consistent pattern [7]. Of particular importance is the maintenance of pressure within the system because this is directly related to the required application rate and droplet size. The uniformity of application becomes an increasingly important factor when irrigating with high salinity water because poor uniformity will result in spatial differences in salinity within the root zone. To achieve a uniformly low salinity level in the root zone requires higher leaching fractions and higher water application. In climates with high evaporation, typical of the summer conditions in the Arabian Peninsula [22], evaporation during application from systems with very fine droplets can be as high as 30%. Salt in the water supply may be 10,000 ppm; however the salinity of the water that is being actually applied can be as high as 13,000 ppm. Systems that apply larger volumes of water with large droplets will significantly reduce this effect. Frequent and small applications of water can lead to salt accumulation at the soil surface, an effect that can be reduced by mulching. Information is available on the performance of most irrigation equipment, and tools are available to monitor the performance of any single system. Applying this information and knowledge to the performance of the equipment being used in the Arabian Peninsula and the influence of local conditions, is vital to the viability of saline irrigation systems [3, 7].

Understanding soil water relationships: Soils in the Arabian Peninsula vary tremendously in their physical and chemical properties and in their response to irrigation; however, most saline irrigation is being practiced in sandy soils [23]. The water holding capacity determines the amount of water held in the soil and thus available for evapo-transpiration. The range is from 0.03 cm^3/cm^3 in coarse sand to over 0.4 cm^3/cm^3 in well-structured loam and clay soils. For point source systems, both the texture of the soil and the rate of water application will influence the distribution of water in the soil profile. For sandy soils the depth of penetration of water will be greater than with clay soils. At higher application rates, so long as the application rates do not exceed the infiltration rates, water will penetrate deeper and move less radially than at low application rates. An understanding of the soil's water holding capacity and water distribution as it is applied are critical to match plant characteristics, such as rooting volume, to the performance of the irrigation system. Soils also vary greatly in their chemical properties and in the way they respond to fertilizer application and toxic substances. In sandy soils nutrients move through the profile quickly and the chances of over irrigation are greater, requiring careful irrigation management to minimize nutrient loss and pollution of the groundwater [14, 19].

Water and salt management in the root zone: The root zones of plants vary according to the characteristics of the plants and the presence of barriers (both physical and chemical) within the soils. These barriers are generally easy to describe through soil surveys, soil analyses or observations and, therefore, irrigation management decisions that are made to ensure water application can meet plant requirements. Critical to the management of water and salt in the root zone is a good understanding of the "root zone"; i.e., the volume of plant roots in the soil and the area that should supply the plant's water needs and contain the minimum of salt [14, 24]. The root zone varies considerably, for example plants with a fibrous root system (grasses, cereals, date palm and many shrubs) generally have most of their roots at the surface, while plants with a tap root (most trees, alfalfa and desert shrubs) have roots distributed deep in the soil profile. While the wetting pattern within a soil will influence the distribution of roots, maximum plant productivity will result where the wetting pattern matches the natural distribution of the plant's roots. The relationship between the salinity of the irrigation water, the soil properties and the leaching requirements that are needed to maintain the salinity levels in the root zone at an acceptable level, are well known. However, it is not necessarily easy to maintain the desired salinity levels due to deficiencies in the irrigation systems, environmental factors or nature of the water supply [8, 18].

Water Needs in the Arabian Peninsula

Imbalances between increasing water demand and existing limited water resources have been experienced by the countries of the Arabian Peninsula for decades [5]. During the last decade, however, water demand in all sectors has increased dramatically as a result of high population growth, higher standard of living, efforts to establish self-sufficiency in food, and promotion of industrial development. The deficit is being met through sea-water desalination and mining of groundwater resources. Currently, agriculture is the primary water consumer, particularly in Saudi Arabia, Yemen, the United Arab Emirates and Oman. Industrial water demand is very small in comparison to the domestic sector. Domestic and industrial water requirements for the countries of Saudi Arabia, Bahrain, Kuwait, Qatar, Oman and the United Arab Emirates, are satisfied through desalination and a limited amount of groundwater from both shallow and deep aquifers [5, 10]; Yemen, however, relies solely on groundwater resources for all sectors [25]. Irrigation requirements are met through abstraction of water from shallow alluvial aquifers located in the coastal areas and inland basins, and from deep aquifers covering most of the Arabian Peninsula. In Saudi Arabia, rapid expansion of agricultural activities has resulted in substantial increases in water demand, leading to extensive mining of the deep aquifers. Likewise, agricultural water demand has sharply increased in Bahrain, Qatar, Oman and the United Arab Emirates, where groundwater reserves are being mined [8, 13]. This agricultural development is a direct result of government policies encouraging self-sufficiency in food production. Government incentives and subsidies have made it possible for large areas to be cultivated, placing great strain on the existing groundwater resources. Total water demand for agricultural, industrial and domestic purposes for all countries in the region increased during the period 1980-1990, from 6.6 to 22.5 bcm, an almost fourfold increase, as a result of high population growth and increased demand for food production. The major consumers were Saudi Arabia, Yemen, the United Arab Emirates and Oman. Water requirements are expected to reach 28.2 bcm by 2010, and 36.7 bcm by 2025. For the Arabian Peninsula as a whole, the demand for agricultural water requirements is estimated at 19.7 bcm in 1990, with demands of 14.6, 2.7, 1.2, and 0.95 bcm in Saudi Arabia, Yemen, Oman and the United Arab Emirates, respectively. In 1990, the percentage of agricultural demand ranged from 21 to 93% of the total water demand. Agricultural water demand is expected to reach 21.2 and 24.3 bcm in the years 2000 and 2025, respectively. Consequently, countries in the Arabian Peninsula will have a water balance of -22,330 million m^3 in 2005 as compared to +18,220 million m^3 in countries of West Asia. This balance, however, will reach -31,910, and +2,470 million m^3 in the Arabian Peninsula and west Asia, respectively in 2015 [7].

Sustainability of Saline Agriculture in the Arabian Peninsula

Sustainability of crop production under salinity is the ability of the crop to continue to produce on a particular saline site and involves the ability to grow, survive and reproduce an economic yield. Another aspect of sustainability is the degree to which carbon can be sequestered in salt tolerant crops and saline soils. Salinity causes the release of greenhouse gases as the vegetation dies back and the above- and below-ground organic matter decays. The credibility of saline agriculture in the Arabian Peninsula and elsewhere, will be confirmed when research organizations develop packages of practices and demonstrate sustainable production based on saline water irrigation [8, 14, 24]. The criteria which will determine its success depends on the extent of adoption by farmers, economic returns and demonstrated environmental benefits. Moreover, the success and long-term sustainability of saline agriculture will depend on continued efforts to select and breed salt tolerant crops using integrated traditional and biotechnological approaches. One of the major issues facing saline agriculture in the Arabian Peninsula is that of environmental impact. Large monocultures have often had negative environmental impacts and this must be avoided at all costs, especially under the fragile environmental conditions in large parts of this region. High yields from salt tolerant crops can be achieved only with high fertilizer and salt water inputs. Proper management, however, can optimize nutrient and water conditions, thus avoiding wastage and the need for excessive leaching. Nevertheless, the overall positive environmental impact of saline agriculture outweighs the negative, as long as saline agriculture is established on marginal or set-aside lands where saline water resources are available [24].

Policy Priorities

Lack of reliable information on the location, extent, and severity of salinity problems in most countries of the Arabian Peninsula limits the ability of governments to formulate appropriate policies and target investment to initiate developmental, control or reclamation projects [10]. Government policies, especially under-pricing of water and distorting subsidies, are among the factors that contribute to the build-up of salinity. Inadequate irrigation scheme designs, which neglected to include a drainage system, also contribute to salinization. National and regional policy priorities [1, 10, 26] should be targeted to (1) increase the use of affordable, small-plot irrigation devices, (2) invest in community-based watershed restoration and rainwater harvesting projects. Such projects can help recharge local groundwater, store runoff for dry-season irrigation, and make irrigation more widely available, and (3) support initiatives to spread low-cost drip irrigation and micro-sprinkler packages for smallholders. Economics is always an important consideration in agricultural production, in general, and in saline agriculture, in particular. Therefore, to encourage the private sector invest in saline agriculture it will be necessary to provide grants, economic and social incentives, and enact legislation for environmental stewardship and sustainability.

Conclusions

The growing regional realization that productive lands are limited and fresh water resources in much of the Arabian Peninsula are overexploited called for the utilization of marginal lands and saline water resources for forage and crop production and for coastal landscaping, sand dune stabilization and to combat desertification. Land and renewable fresh water resources are limited and are being exploited at a rapid rate, with agriculture utilizing >85% of fresh water resources. Consequently, policy makers and planners were forced to search for alternative natural resources for agricultural production. Saline and brackish water resources, marginal lands and plants capable of growing and producing an economic crop under the harsh climate of the Arabian Peninsula, are abundant and expected to alleviate the mounting pressures on fresh water resources and prime agricultural lands. There is a need to demonstrate the value of saline water resources for the production of environmentally and economically useful plants and crops and to transfer the results to national research services and communities in the Arabian Peninsula and elsewhere. Accumulated scientific knowledge on and availability of salt tolerant plants along with the need for new management practices appropriate for saline agriculture justified this approach in order to develop, coordinate and disseminate information on saline agricultural technology. However, there is still a critical lack of applied research that combines biological, physical, economic and social variables at the farm level. A strategy was designed to develop improved irrigation systems, water management, control of salinity within the root zone and utilization of genetic resources of salt tolerant plants and halophytes. This integrated and holistic approach reflects local and regional ecosystems' relationships, addresses the long-term sustainability of saline agriculture and aims at (1) developing models, predictions and decision-support systems for saline agriculture, (2) providing flexible and efficient means for evaluating alternative options in saline agricultural production, and (3) developing packages of production practices for specific eco-geographical and socio-economic target regions and subsistence farmers.

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